ENGINEERING DEVELOPMENT OF COAL-FIRED HIGH-PERFORMANCE POWER SYSTEMS

DE-AC22-95PC95143

TECHNICAL PROGRESS REPORT NO. 17
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ABSTRACT

A High Performance Power System (HIPPS) is being developed. This system is a coal-fired, combined cycle plant with indirect heating of gas turbine air. Foster Wheeler Development Corporation and a team consisting of Foster Wheeler Energy Corporation, Bechtel Corporation, University of Tennessee Space Institute and Westinghouse Electric Corporation are developing this system. In Phase 1 of the project, a conceptual design of a commercial plant was developed. Technical and economic analyses indicated that the plant would meet the goals of the project which include a 47 percent efficiency (HHV) and a 10 percent lower cost of electricity than an equivalent size PC plant.

The concept uses a pyrolysis process to convert coal into fuel gas and char. The char is fired in a High Temperature Advanced Furnace (HITAF). The HITAF is a pulverized fuel-fired boiler/air heater where steam is generated and gas turbine air is indirectly heated. The fuel gas generated in the pyrolyzer is then used to heat the gas turbine air further before it enters the gas turbine.

The project is currently in Phase 2 which includes engineering analysis, laboratory testing and pilot plant testing. Research and development is being done on the HIPPS systems that are not commercial or being developed on other projects. Pilot plant testing of the pyrolyzer subsystem and the char combustion subsystem are being done separately, and after each experimental program has been completed, a larger scale pyrolyzer will be tested at the Power Systems Development Facility (PSDF) in Wilsonville, AL. The facility is equipped with a gas turbine and a topping combustor, and as such, will provide an opportunity to evaluate integrated pyrolyzer and turbine operation.

This report addresses the areas of technical progress for this quarter. Preliminary work began to plan the conversion of the bubbling fluidized bed pilot plant in Livingston, New Jersey to a circulating mode of operation. The circulating fluidized bed will allow for easy scale-up to larger size plants. The existing pyrolyzer will be outfitted with a cyclone and a j-valve to capture and reinject char into the lower combustion zone. The repowering of an existing PC boiler provides a unique opportunity for the near-term application of the HIPPS technology. Further study of the repowering arrangement suggests that efficiencies greater than 45% are possible.

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EXECUTIVE SUMMARY

The High Performance Power System is a coal-fired, combined cycle power generating system that will have an efficiency of greater than 47 percent (HHV) with NOx and SOx less than 0.025 Kg/GJ (0.06 lb/MMBtu). This performance is achieved by combining a coal pyrolysis process with a High Temperature Advanced Furnace (HITAF). The pyrolysis process consists of a pressurized fluidized bed reactor which is operated at about 926^{o}C (1700^{o}F) at substoichiometric conditions. This process converts the coal into a low-Btu fuel gas and char. These products are then separated.

The char is fired in the HITAF where heat is transferred to the gas turbine compressed air and to the steam cycle. The HITAF is fired at atmospheric pressure with pulverized fuel burners. The combustion air is from the gas turbine exhaust stream. The fuel gas from the pyrolysis process is fired in a Multi-Annular Swirl Burner (MASB) where it further heats the gas turbine air leaving the HITAF. This type of system results in very high efficiency with coal as the only fuel.

We are currently in Phase 2 of the project. In Phase 1, a conceptual plant design was developed and analyzed both technically and economically. The design was found to meet the project goals. The purpose of the Phase 2 work is to develop the information needed to design a prototype/commercial plant. Phase 3 of the overall HIPPS contract has been deleted. In addition to engineering analysis and laboratory testing, the subsystems that are not commercial or being developed on other projects will be tested at pilot plant scale. The FWDC Second-Generation PFB pilot plant in Livingston, NJ, has been modified to test the pyrolyzer subsystem. The FWDC Combustion and Environmental Test Facility (CETF) in Dansville, NY, has been modified to test the char combustion system. Integrated operation of a larger scale pyrolyzer and a commercial gas turbine are planned for the PSDF in Wilsonville, AL.

Planning has begun to modify the bubbling bed pilot plant to operate as a circulating fluidized bed. The circulating fluidized bed affords easier component scale-up, and enhanced fuel flexibility. Further investigation suggests that the overall efficiency of a repowered PC boiler can be increased beyond 45%.

INTRODUCTION

In Phase 1 of the project, a conceptual design of a coal-fired high performance power system was developed, and small scale R&D was done in critical areas of the design. The current Phase of the project includes development through the pilot plant stage.

Foster Wheeler Development Corporation (FWDC) is leading a team of companies in this effort. These companies are:

- Foster Wheeler Energy Corporation (FWEC)
- Bechtel Corporation
- Westinghouse Electric Corporation

The power generating system being developed in this project will be an improvement over current coal-fired systems. Goals have been identified that relate to the efficiency, emissions, costs and general operation of the system. These goals are:

- Total station efficiency of at least 47 percent on a higher heating value basis.
- Emissions:

  NOx < 0.06 lb/MMBtu
  SOx < 0.06 lb/MMBtu
  Particulates < 0.003 lb/MMBtu

- All solid wastes must be benign with regard to disposal.
- Over 95 percent of the total heat input is ultimately from coal, with initial systems capable of using coal for at least 65 percent of the heat input.

The base case arrangement of the HIPPS cycle is shown in Figure 1. It is a combined cycle plant. This arrangement is referred to as the All Coal HIPPS because it does not require any other fuels for normal operation. A fluidized bed, air blown pyrolyzer converts coal into fuel gas and char. The char is fired in a high temperature advanced furnace (HITAF) which heats both air for a gas turbine and steam for a steam turbine. The air is heated up to 760°C (1400°F) in the HITAF, and the tube banks for heating the air are constructed of alloy tubes. The fuel gas from the pyrolyzer goes to a topping combustor where it is used to raise the air entering the gas turbine to 1288°C (2350°F). In addition to the HITAF, steam duty is achieved with a heat recovery steam generator (HRSG) in the gas turbine exhaust stream and economizers in the HITAF flue gas exhaust stream.

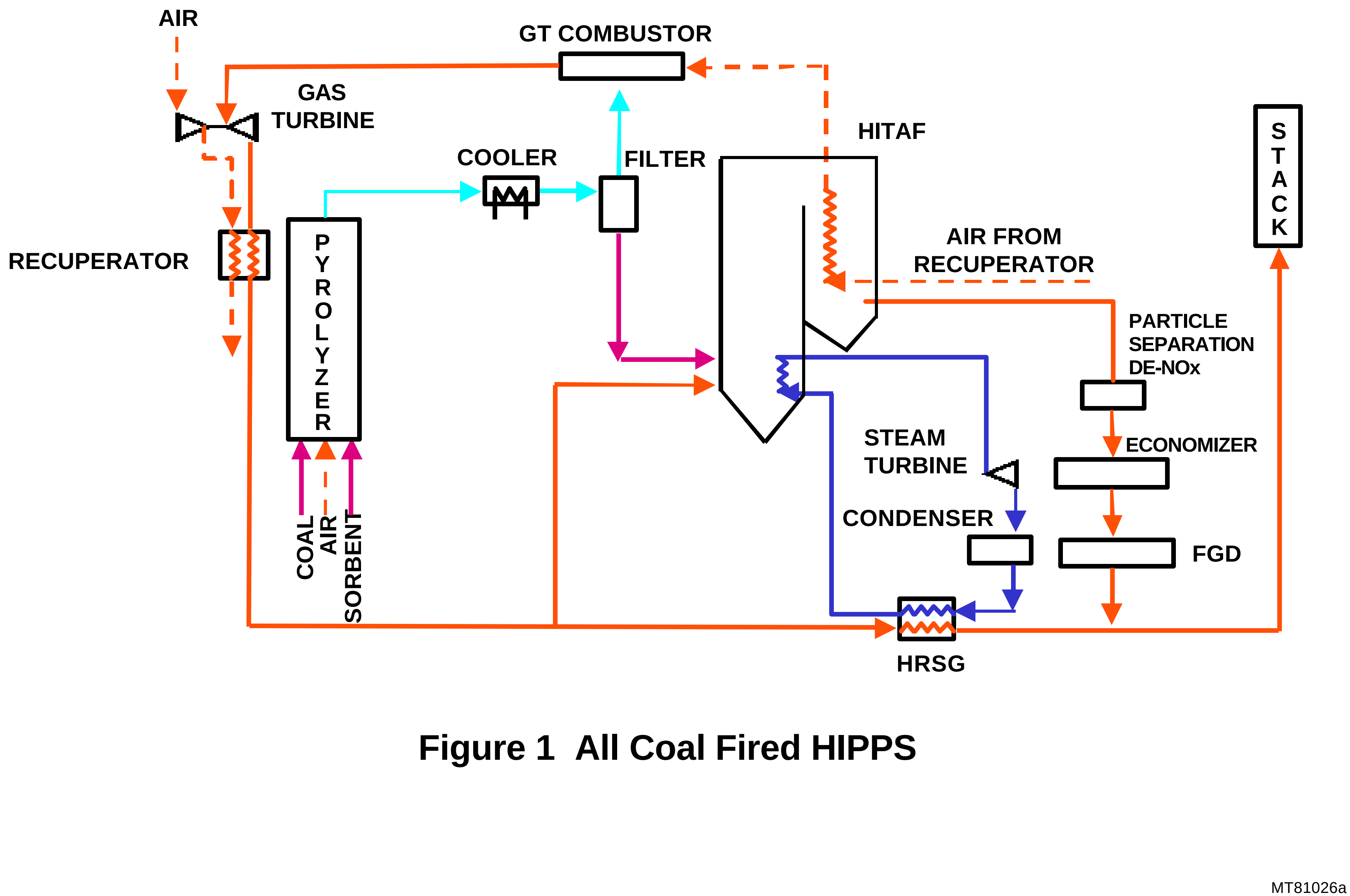

Figure 1 All Coal Fired HIPPS

An alternative HIPPS cycle is shown in Figure 2. This arrangement uses a ceramic air heater to heat the air to temperatures above what can be achieved with alloy tubes. This arrangement is referred to as the 35 percent natural gas HIPPS, and a schematic is shown in Figure 2. A pyrolyzer is used as in the base case HIPPS, but the fuel gas generated is fired upstream of the ceramic air heater instead of in the topping combustor. Gas turbine air is heated to 760^{o}C (1400^{o}F) in alloy tubes the same as in the All Coal HIPPS. This air then goes to the ceramic air heater where it is heated further before going to the topping combustor. The temperature of the air leaving the ceramic air heater will depend on technological developments in that component. An air exit temperature of 982^{o}C (1800^{o} F) will result in 35 percent of the heat input from natural gas.

A simplified version of the HIPPS arrangement can be applied to existing boilers. Figure 3 outlines the potential application of the HIPPS technology for repowering existing pulverized coal fired plants. In the repowering application, the gas turbine exhaust stream provides the oxidant for co-fired combustion of char and coal. The existing boiler and steam turbine infrastructure remain intact. The pyrolyzer, ceramic barrier filter, gas turbine, and gas turbine combustor are integrated with the existing boiler to improve overall plant efficiency and increase generating capacity.

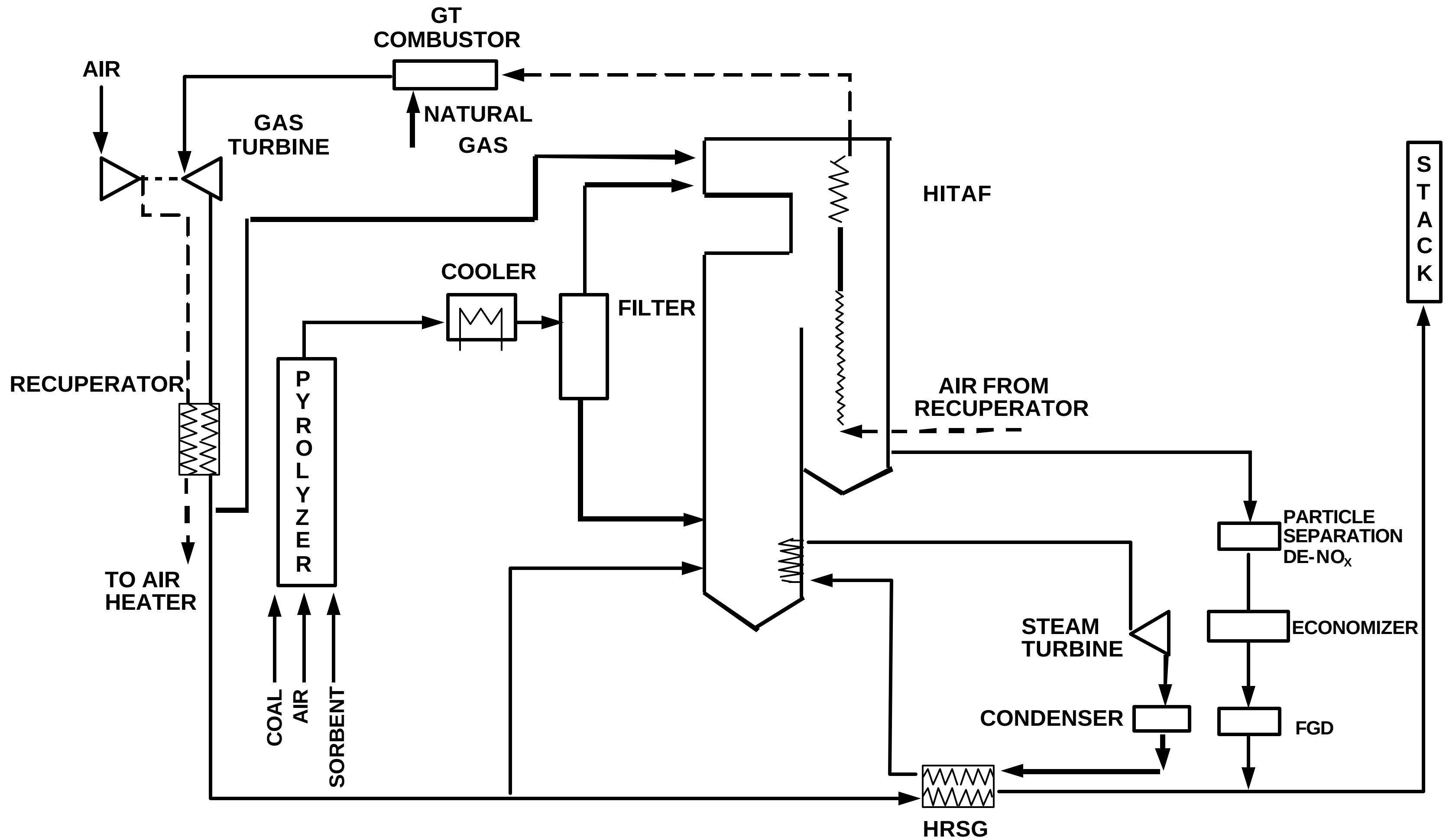

Figure 2 35-Percent Natural Gas HIPPS

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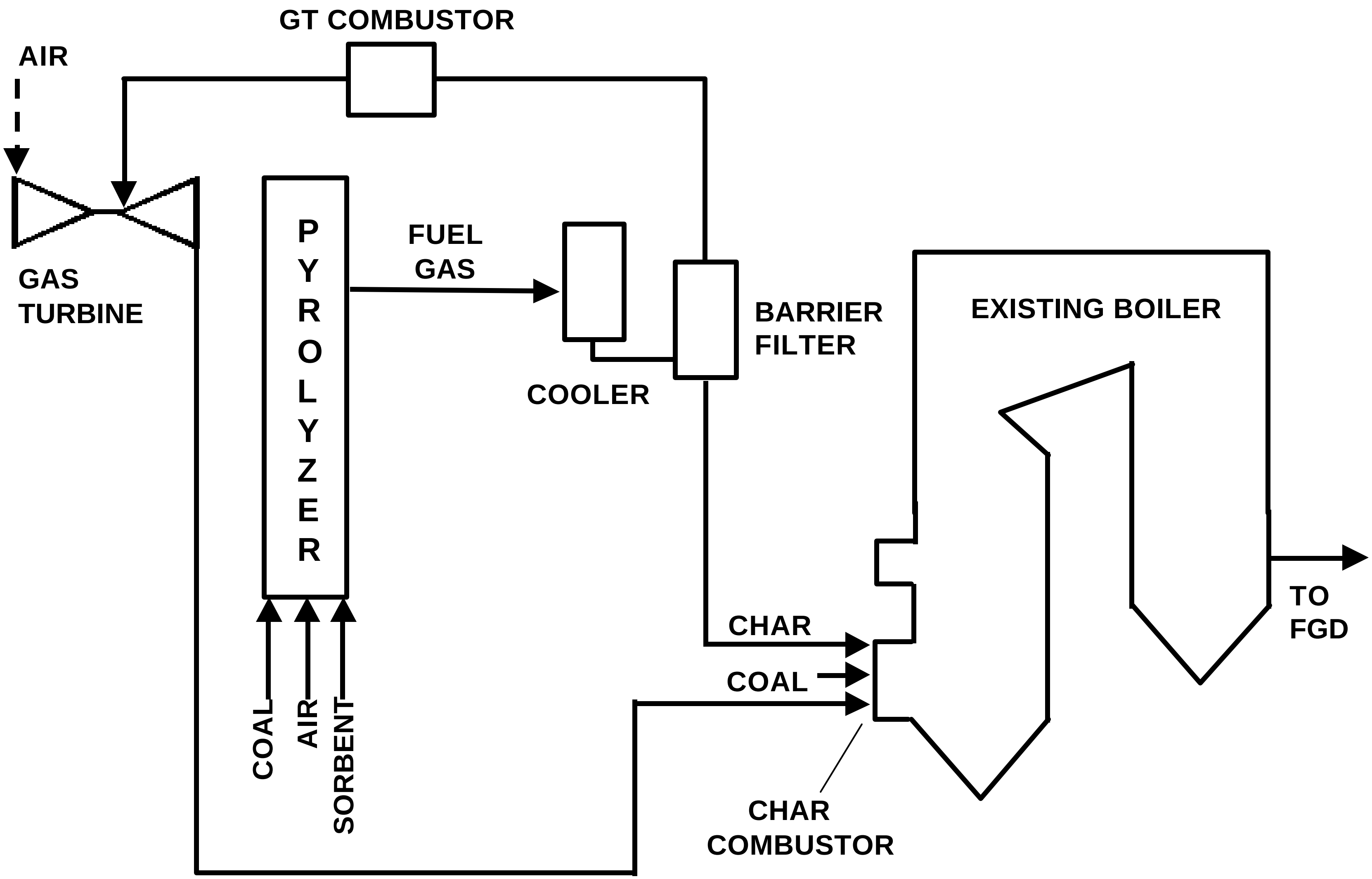

Figure 3 Simplified HIPPS Repowering Process Flow Diagram

TECHNICAL PROGRESS

Task 1 - Project Planning and Management

Subtask 1.1 – Livingston PFB Pilot Plant Design

In fiscal year 2000, HIPPS pyrolyzer testing at FWDC's PFB Pilot Plant Facility in Livingston, NJ is scheduled to take place. The bubbling bed pyrolyzer arrangement previously tested is to be retrofitted to operate as a circulating fluidized bed. The purpose of the test program is to demonstrate stable hydrodynamic performance and steady fuel gas composition. The circulating bed pyrolyzer is easier to scale up to commercial sized applications than the bubbling bed system, and, as such, has broader market potential. During this quarter, a project schedule was devised to prepare the unit for the upcoming testing.

The scope of work to modify the bubbling bed pyrolyzer to circulating fluidized bed mode has been broken down into twelve (12) tasks. Figure 4 depicts a proposed project schedule broken into the following tasks: pyrolyzer refractory design, back end control valve, re-circulation arrangement, sampling probes, flame arrestors, feed system, DCS, materials handling, environmental compliance, utilities, safety, and test plan. The schedule assumes work commencing the Monday of the first full week in fiscal year 2000, October 4, 1999. Contingencies are built into each of the tasks. As shown in Figure 4, HIPPS testing on the circulating fluidized bed pyrolyzer can begin as early as March 2000.

Task 3 - Subsystem Test Unit Design

Subtask 3.1 – Repowering Technology Development

Subtask 3.1.1 – Pyrolyzer Refractory Design

Figure 5 represents the schedule for the modifications required on the pyrolyzer refractory. The current pyrolyzer vessel was designed for bubbling bed operation, and has a varying internal diameter, from a 10" ID at the bottom to a 14" ID at the top. For circulating mode, the vessel ID will need to be modified to a constant ID. Calculations will be made to determine the proper ID that will correspond to the range of riser velocities that will be studied during testing.

The drain boot segment of the pyrolyzer may need to be modified to accommodate the new inner diameter. Design work will be performed if modifications are necessary. Similarly, the instrumentation penetrations in the pyrolyzer vessel will need to be modified to accommodate the change in inner diameter.

The refractory will need to be selected, a curing procedure developed, and a subcontractor identified. Then, once the vessel is removed from the support structure, the unit will be shipped out to be re-lined. This task is identified as one of the critical path items due to the lead-time required for refractory lined pressure vessels. The completion date for this task coincides with the completion of the entire scope of work, March 3, 2000.

Subtask 3.1.2 – Back End Control Valve

The current operation of the pyrolyzer under bubbling bed operation utilizes a fixed flow orifice on the back end of the unit to control unit pressure. In a circulating mode of operation, the riser velocities will be varied as a test parameter and therefore a variable back end control valve will need to be designed. A parallel stream to the current fixed orifice will be installed and, due to the material constraints of a control valve, a gas cooler will be installed on the line to the valve.

Design work will be required for the gas cooler, the valve, and the associated piping for the valve. A safety review of the final design will be performed as well as a heat transfer study of the fuel gas. Process and instrumentation diagrams (P&ID's) will be generated as well. Figure 6 shows the scheduling of this task.

Subtask 3.1.3 – Re-Circulation Arrangement

The modification of the unit to install the re-circulation loop is the critical path of the project, Figure 7 shows the scheduling of this task. Engineering design work is required on the cyclone and J-valve. These items have been fabricated based on original project criterion and require design review. Modifications to, or removal of, the classifier is required and a heat exchanger needs to be designed for the re-circulation loop. Engineering effort will also be placed in the following areas: design of J-valve solids sampling, piping arrangement, P&ID's, modifications to crane, structural steel modifications, detailed steel fabrication drawings, and instrumentation specification.

For scheduling purposes, the engineering time required for this task has been divided between two individuals. As shown in Figure 7, the completion date for this task is coincident with the completion date for the entire scope of work, March 3, 2000.

Subtask 3.1.4 – Sampling Probes

As part of the test program, alkali levels in the fuel gas are measured. Similarly, if pet coke is used as a feed stock to the pyrolyzer, levels of heavy metals, such as vanadium and mercury, would need to be measured in the fuel gas stream. An alkali probe was used during testing of the bubbling bed pyrolyzer and its design needs to be reviewed, and possible modifications made before using in a circulating mode.

A heavy metal probe would have to be designed and built for use during testing. Process and instrumentation diagrams need to be generated for the probe, instrumentation for the probe needs to be specified, and a sampling procedure developed. Figure 8 shows the schedule for this task.

Subtask 3.1.5 – Flame Arrestors

The pilot plant facility in Livingston utilizes a thermal-oxidizer in the stack to combust the fuel gas generated in the pyrolyzer. Due to the nature of the process and layout of the facility, the threat of flame propagation back into the system exists. The flame arrestor design used for previous testing interfered with the process flow and became a safety hazard by providing too much backpressure on the baghouse as it became plugged. To prevent this event from occurring again, a new flame arrestor system needs to be designed and installed. Figure 9 shows the schedule for this task.

Subtask 3.1.6 – Feed System

A review of the existing feed system is needed to address feed problems experienced with previous test programs. Any design modifications necessary will be addressed at this time. A transport line DP measuring system, used as an indication of feed stream plugging, needs to be designed and installed and a procedure for troubleshooting feed system problems will be developed. Figure 10 shows the scheduling for this task.

Subtask 3.1.7 – DCS

The distributed control system, DCS, will need upgrading for Y2K compliance and to accommodate the new equipment for the re-circulation loop. An open input and output, I/O, count needs to be performed so additional I/O modules can be specified and purchased. A point-to-point check of existing I/O needs to be performed to verify that all current instrumentation is calibrated and operating correctly as well.

Graphics screens and control logic will need to be programmed for the new re-circulation loop equipment. Wiring diagrams for the new facility equipment will be developed and the DCS will be programmed to produce reports required by the DEC. Operators will be trained on the new DCS equipment and on controlling new process equipment. The scheduling for this task is shown in Figure 11.

Subtask 3.1.8 – Materials Handling

The feed stocks for the pyrolyzer need to be identified and procured. The preferred chemical compositions need to be determined as well as the correct particle size distributions, PSD. A sampling procedure for feed stocks needs to be addressed as well as the analyses to be performed on these samples. The schedule for this task is shown in Figure 12.

Subtask 3.1.9 – Environmental Compliance

As part of the permitting required to operate the pilot plant facility, a stack test needs to be performed while under operation. The permits to operate the plant need to be reviewed and this stack test will be scheduled. The continuous emissions monitors, CEM's, need to be calibrated, the calibration gases procured, and the associated piping reviewed.

The char produced needs to be handled appropriately. A solids removal plan will be formulated and storage drums procured. Material Safety Data Sheets for the char material will be developed for transportation purposes, as the char may be combusted at FWDC's test facility in Dansville, NY. The schedule for this task is outlined in Figure 13.

Subtasks 3.1.10-12 – Utilities, Safety, and Test Plan

The peripheral utilities associated with operation of the pilot plant facility need to be reviewed and maintenance work performed to prepare for testing. These utilities include nitrogen system, steam supply system, process air system, and instrument air system. Vendors associated with each system will be brought in to perform the necessary work.

A safety review of the facility will be performed to ensure compliance with all OSHA and related standards. Pressure vessel safety valves will be sent to manufacturers for re-certification. The following personnel safety systems will be reviewed: air pack stations, eye wash system, ambient air monitor calibration, and fire protection system.

Testing parameters need to be isolated and a test matrix developed to optimize unit operation. Figure 14 contains the schedule for the above tasks.

ID	Task Name	Start	Finish
1	**PFB Circulating Mode Modifications**	**Mon 10/4/99**	**Fri 3/3/00**
2	**Pyrolyzer Refractory Design**	**Mon 10/4/99**	**Fri 3/3/00**
21	**Back End Control Valve**	**Mon 10/4/99**	**Fri 1/28/00**
38	**Re-Circulation Arrangement**	**Mon 10/4/99**	**Fri 3/3/00**
70	**Sampling Probes**	**Mon 10/4/99**	**Fri 2/4/00**
87	**Flame Arrestors**	**Mon 10/4/99**	**Fri 11/12/99**
99	**Feed System**	**Mon 10/4/99**	**Fri 1/7/00**
110	**DCS**	**Mon 10/4/99**	**Fri 2/25/00**
135	**Materials Handling**	**Mon 10/4/99**	**Thu 1/6/00**
147	**Environmental Compliance**	**Mon 10/4/99**	**Fri 12/3/99**
162	**Utilities**	**Mon 10/4/99**	**Fri 12/17/99**
167	**Safety**	**Mon 10/4/99**	**Fri 11/12/99**
174	**Test Plan**	**Mon 10/4/99**	**Fri 11/19/99**

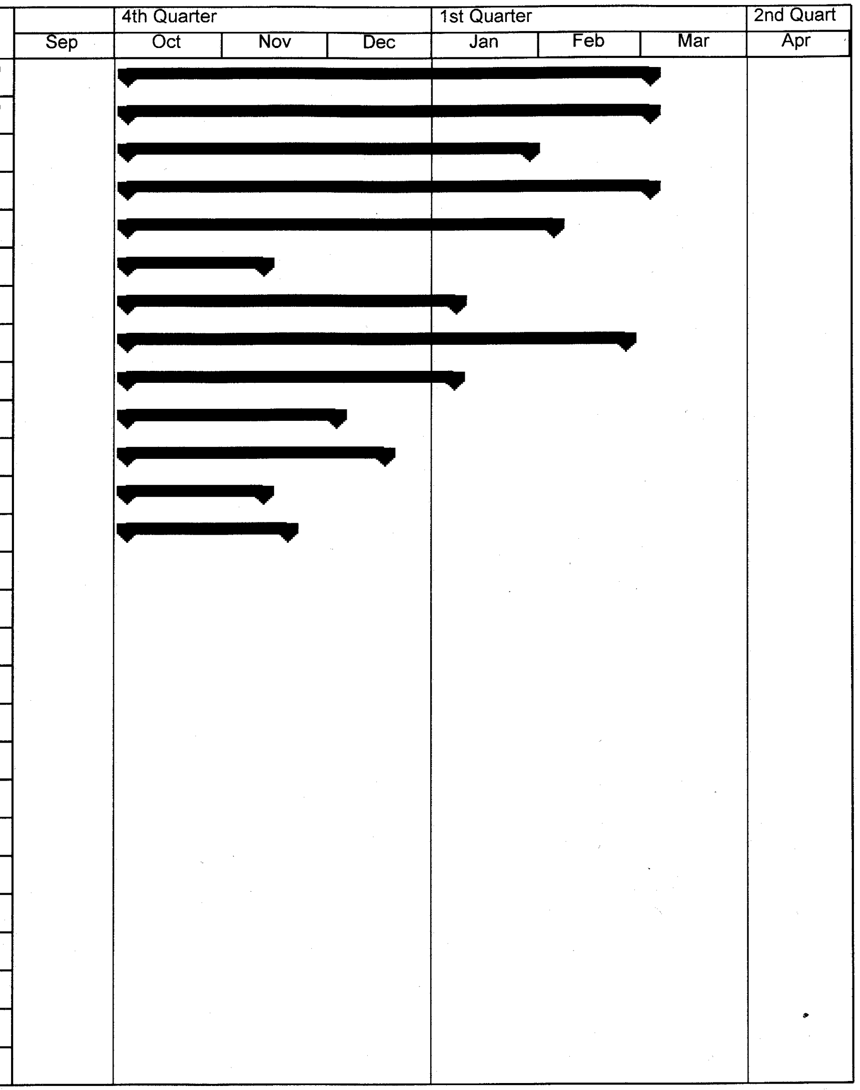

Figure 4. PFB Modifications Schedule

ID	Task Name	Start	Finish
1	**Pyrolyzer Refractory Design**	**Mon 10/4/99**	**Fri 3/3/00**
2	**Engineering**	**Mon 10/4/99**	**Fri 11/5/99**
3	Review riser velocity	Mon 10/4/99	Fri 10/8/99
4	Review drain boot design	Mon 10/4/99	Fri 10/8/99
5	Refractory selection	Mon 10/11/99	Fri 10/15/99
6	Identify subcontractor	Mon 10/11/99	Tue 10/12/99
7	Refractory curing procedure	Mon 10/18/99	Fri 10/22/99
8	Instrumentation modification	Mon 10/25/99	Fri 11/5/99
9	**Demolition**	**Mon 10/4/99**	**Fri 10/29/99**
10	Remove roof	Mon 10/11/99	Fri 10/22/99
11	Disconnect Instrumentation/Piping	Mon 10/4/99	Fri 10/15/99
12	Remove pyrolyzer	Mon 10/25/99	Fri 10/29/99
13	**Procurement**	**Mon 10/4/99**	**Fri 1/21/00**
14	Refractory outsource	Mon 11/1/99	Fri 1/21/00
15	Crane Rental	Mon 10/4/99	Fri 10/8/99
16	Instrumentation	Mon 11/8/99	Fri 12/31/99
17	**Installation**	**Mon 1/24/00**	**Fri 3/3/00**
18	Pyrolyzer installation	Mon 1/24/00	Fri 2/11/00
19	Instrumentation	Mon 2/14/00	Fri 3/3/00

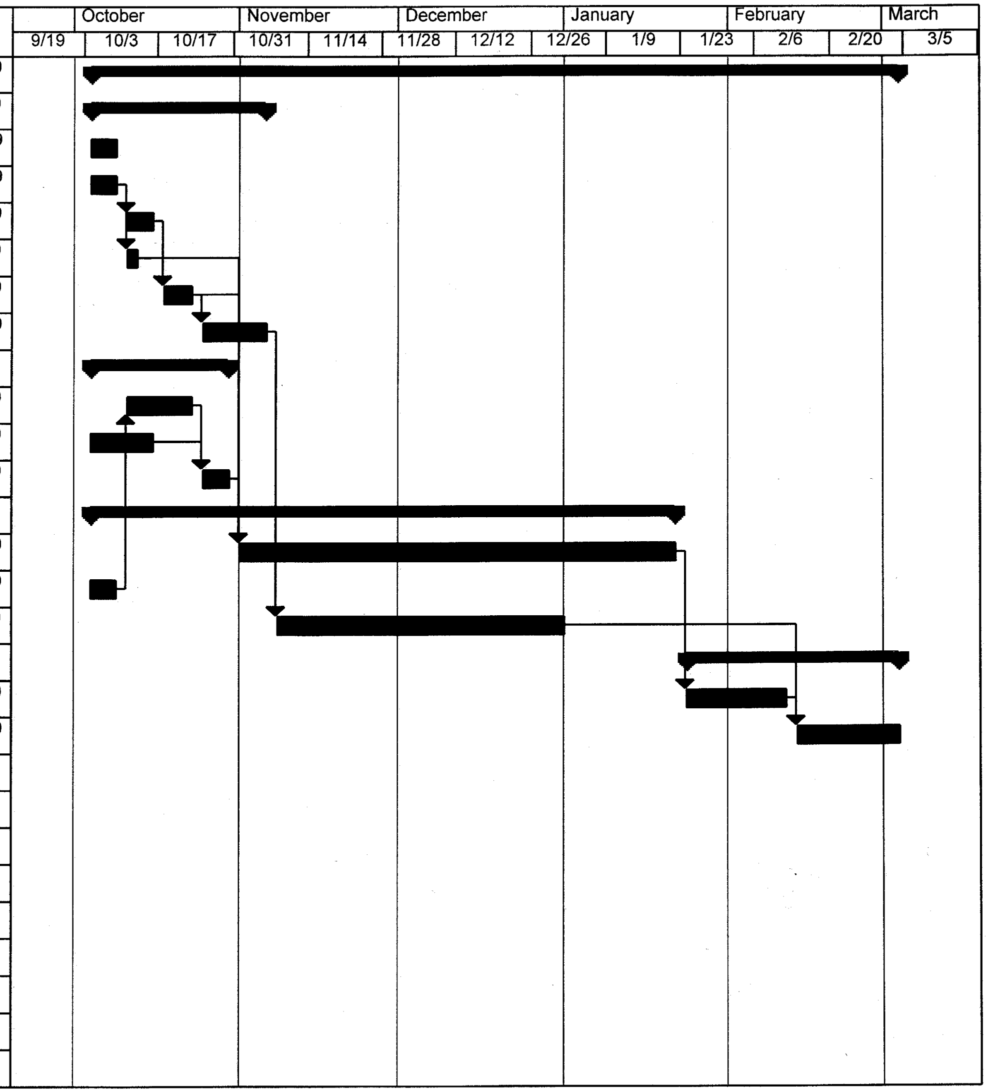

Figure 5. Subtask 3.1.1 Schedule

ID	Task Name	Start	Finish
1	**Back End Control Valve**	**Mon 10/4/99**	**Fri 1/28/00**
2	**Engineering**	**Mon 10/4/99**	**Fri 10/22/99**
3	Design valve	Mon 10/4/99	Fri 10/8/99
4	Design piping arrangement	Mon 10/4/99	Fri 10/15/99
5	Review gas cooler design	Mon 10/4/99	Fri 10/8/99
6	Review safety design	Mon 10/4/99	Fri 10/8/99
7	Heat transfer study	Mon 10/4/99	Fri 10/8/99
8	P&ID	Mon 10/18/99	Fri 10/22/99
9	**Procurement**	**Mon 10/25/99**	**Fri 1/14/00**
10	Refractory lined spool pieces	Mon 10/25/99	Fri 1/14/00
11	Control valves (steam & gas)	Mon 10/25/99	Fri 12/17/99
12	Shut-off valve (steam & gas)	Mon 10/25/99	Fri 12/17/99
13	Instrumentation (steam & gas)	Mon 10/25/99	Fri 12/17/99
14	**Installation**	**Mon 1/17/00**	**Fri 1/28/00**
15	Refractory lined piping	Mon 1/17/00	Fri 1/28/00
16	Steam piping	Mon 1/17/00	Fri 1/28/00
17	Instrumentation	Mon 1/17/00	Fri 1/28/00

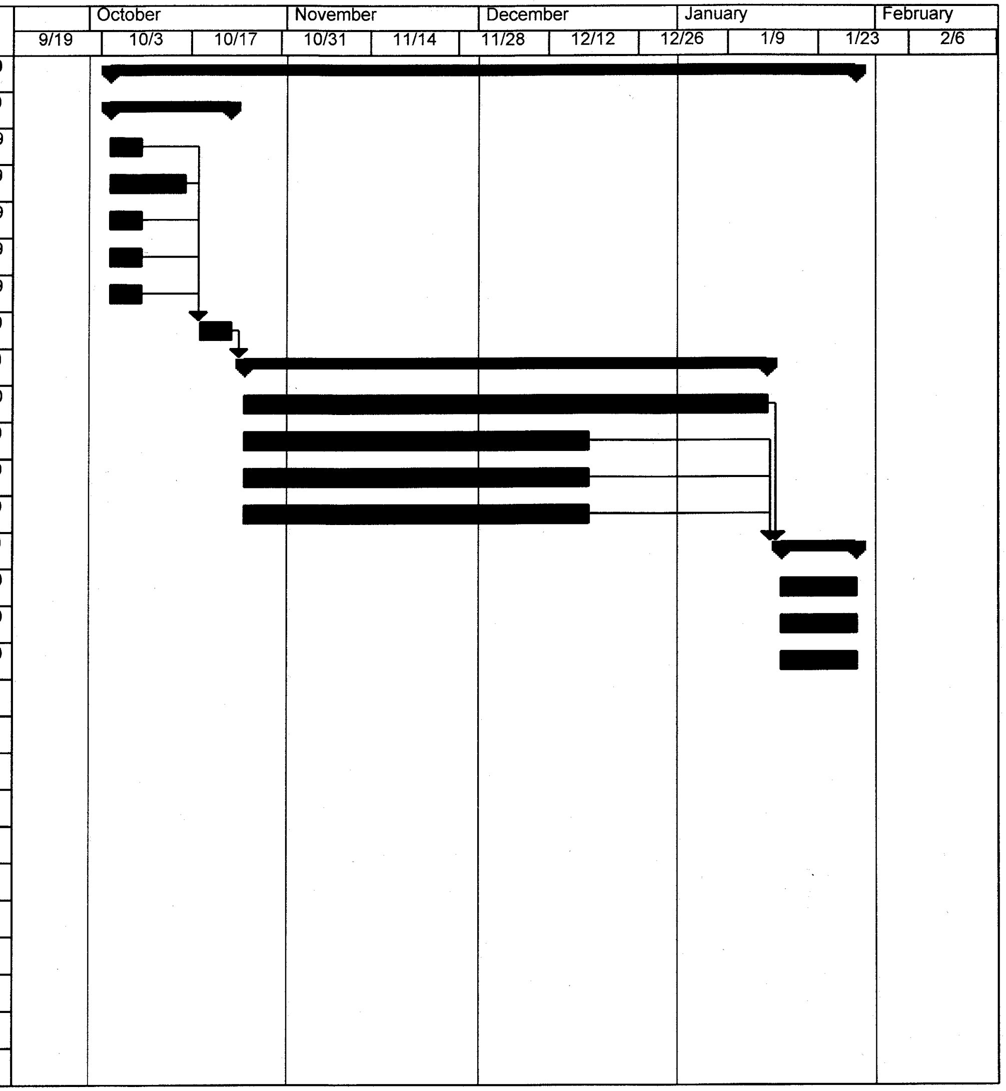

Figure 6. Subtask 3.1.2 Schedule

ID	Task Name	Start	Finish
1	**Re-Circulation Arrangement**	**Mon 10/4/99**	**Fri 3/3/00**
2	**Engineering**	**Mon 10/4/99**	**Fri 12/31/99**
3	Review cyclone design	Mon 10/4/99	Fri 10/15/99
4	Review J-Valve design	Mon 10/4/99	Fri 10/15/99
5	System pressure balance	Mon 10/18/99	Fri 10/22/99
6	Classifier modifications	Mon 10/18/99	Fri 10/22/99
7	Design of heat exchanger	Mon 10/25/99	Fri 11/12/99
8	Design J-Valve solids sampling	Mon 10/25/99	Fri 11/5/99
9	Design piping arrangement	Mon 11/8/99	Fri 11/19/99
10	P&ID's	Mon 11/22/99	Fri 12/3/99
11	Crane modification	Mon 11/15/99	Fri 11/19/99
12	Structural steel modifications	Mon 11/22/99	Fri 12/3/99
13	Temperature sensative paint	Mon 10/4/99	Mon 10/4/99
14	Detailed steel fabrication drawings	Mon 12/6/99	Fri 12/31/99
15	Instrumentation	Mon 12/6/99	Fri 12/17/99
16	**Procurement**	**Tue 10/5/99**	**Fri 2/11/00**
17	Refractory lined pipe	Mon 11/22/99	Fri 2/11/00
18	Small piping	Mon 11/22/99	Fri 1/14/00
19	Structural steel	Mon 12/6/99	Fri 1/28/00
20	Instrumentation	Mon 12/20/99	Fri 2/11/00
21	Paint	Tue 10/5/99	Mon 11/29/99
22	**Demolition**	**Mon 10/4/99**	**Fri 10/29/99**
23	Structural steel	Mon 10/4/99	Fri 10/15/99
24	Relocate instrumentation/wiring	Mon 10/4/99	Fri 10/29/99
25	Remove classifier?	Mon 10/18/99	Fri 10/22/99
26	Remove paste feed system?	Mon 10/18/99	Fri 10/29/99
27	**Installation**	**Mon 1/17/00**	**Fri 3/3/00**

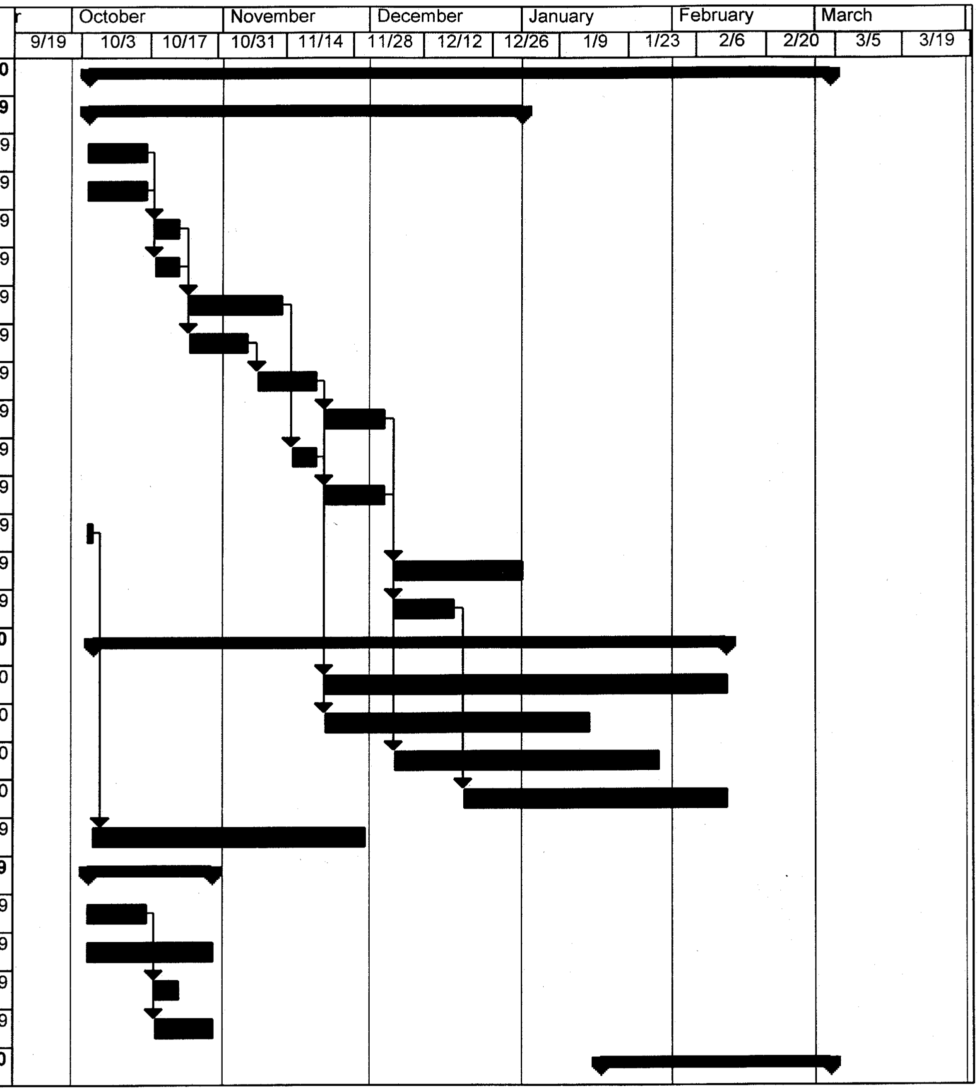

Figure 7. Subtask 3.1.3 Schedule

ID	Task Name	Start	Finish
1	**Sampling Probes**	**Mon 10/4/99**	**Fri 2/4/00**
2	**Engineering**	**Mon 10/4/99**	**Fri 12/10/99**
3	Identify subcontractor	Mon 10/4/99	Fri 10/8/99
4	Heavy metal probe design	Mon 10/11/99	Fri 10/29/99
5	Review design of alkali probe	Mon 11/1/99	Fri 11/12/99
6	P&ID's	Mon 11/15/99	Fri 11/19/99
7	Instrumentation	Mon 11/22/99	Fri 11/26/99
8	Locate sample penetrations	Mon 10/4/99	Mon 10/4/99
9	Develop sampling procedures	Mon 11/29/99	Fri 12/10/99
10	**Procurement**	**Mon 11/1/99**	**Fri 1/21/00**
11	Heavy Metal Probe	Mon 11/1/99	Fri 1/21/00
12	Small piping	Mon 11/22/99	Fri 1/14/00
13	Instrumentation	Mon 11/29/99	Fri 1/21/00
14	**Installation**	**Mon 1/17/00**	**Fri 2/4/00**
15	Heavy Metal Probe	Mon 1/24/00	Fri 2/4/00
16	Small piping	Mon 1/17/00	Fri 1/21/00
17	Instrumentation	Mon 1/24/00	Fri 2/4/00

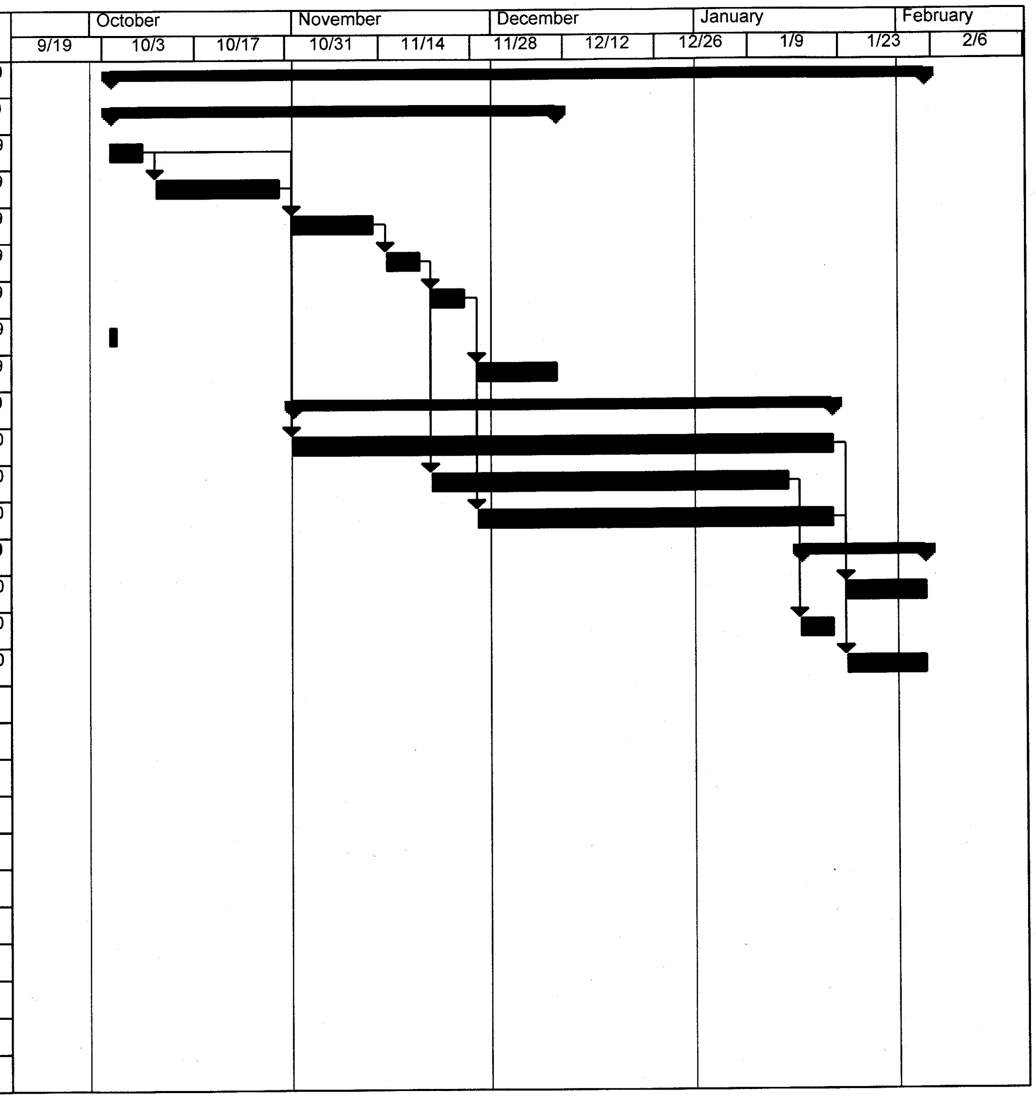

Figure 8. Subtask 3.1.4 Schedule

ID	Task Name	Start	Finish
1	**Flame Arrestors**	**Mon 10/4/99**	**Fri 11/12/99**
2	**Engineering**	**Mon 10/4/99**	**Fri 10/22/99**
3	Piping Layout (process and N2)	Mon 10/4/99	Fri 10/8/99
4	Develop operating procedure	Mon 10/11/99	Fri 10/15/99
5	Instrumentation	Mon 10/18/99	Fri 10/22/99
6	**Procurement**	**Mon 10/4/99**	**Fri 11/5/99**
7	Arrestors	Mon 10/4/99	Fri 10/29/99
8	Small piping	Mon 10/11/99	Fri 11/5/99
9	**Installation**	**Mon 11/1/99**	**Fri 11/12/99**
10	Arrestors	Mon 11/1/99	Fri 11/5/99
11	N2 piping	Mon 11/8/99	Fri 11/12/99
12	Instrumentation	Mon 11/8/99	Tue 11/9/99

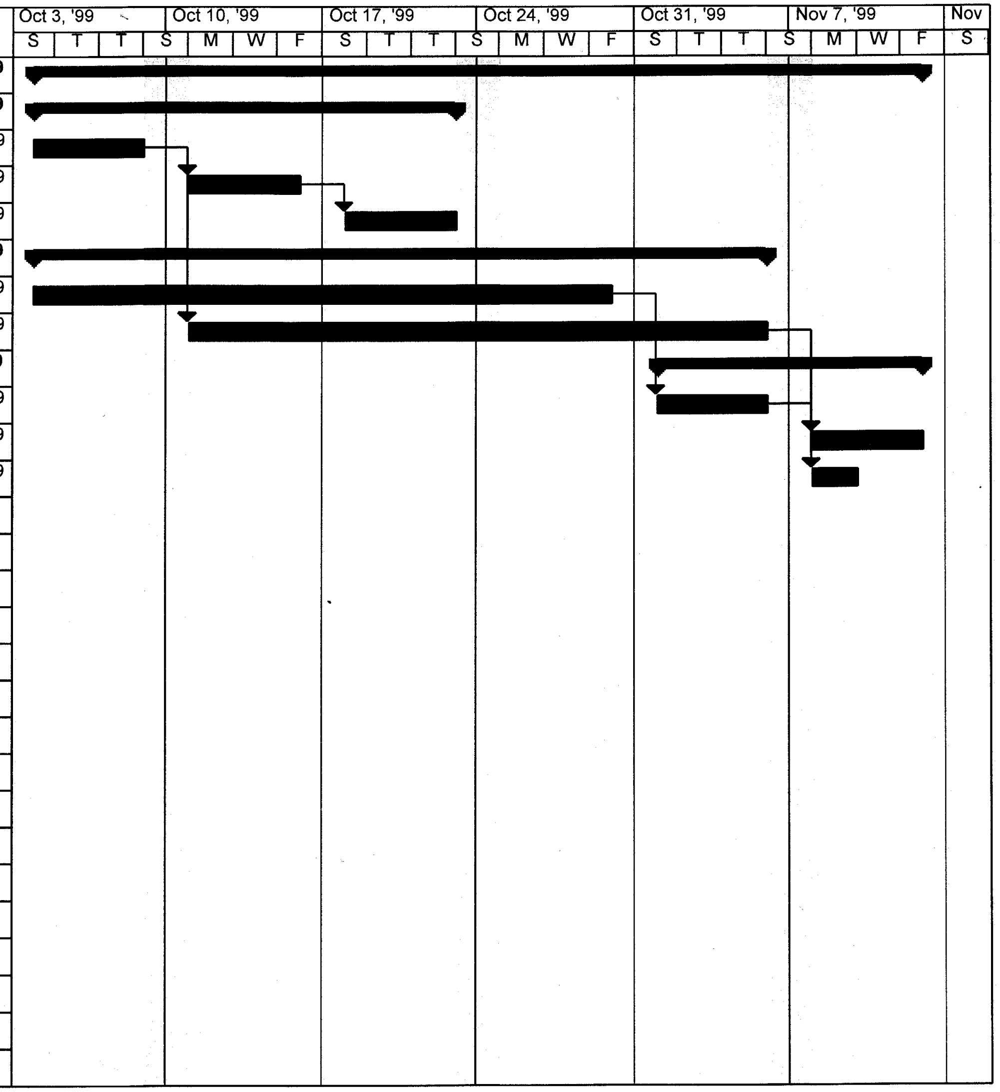

Figure 9. Subtask 3.1.5 Schedule

ID	Task Name	Start	Finish
1	**Feed System**	**Mon 10/4/99**	**Fri 1/7/00**
2	**Engineering**	**Mon 10/4/99**	**Fri 11/12/99**
3	Review existing design	Mon 10/4/99	Fri 10/15/99
4	Design modifications	Mon 10/18/99	Fri 10/29/99
5	Transport line DP system	Mon 11/1/99	Fri 11/5/99
6	Troubleshooting procedure	Mon 11/8/99	Fri 11/12/99
7	**Procurement**	**Mon 11/1/99**	**Fri 12/24/99**
8	Shear pins	Mon 11/1/99	Fri 12/24/99
9	Grounded hoses	Mon 11/1/99	Fri 12/24/99
10	**Installation**	**Mon 12/27/99**	**Fri 1/7/00**
11	Equipment retrofit	Mon 12/27/99	Fri 1/7/00

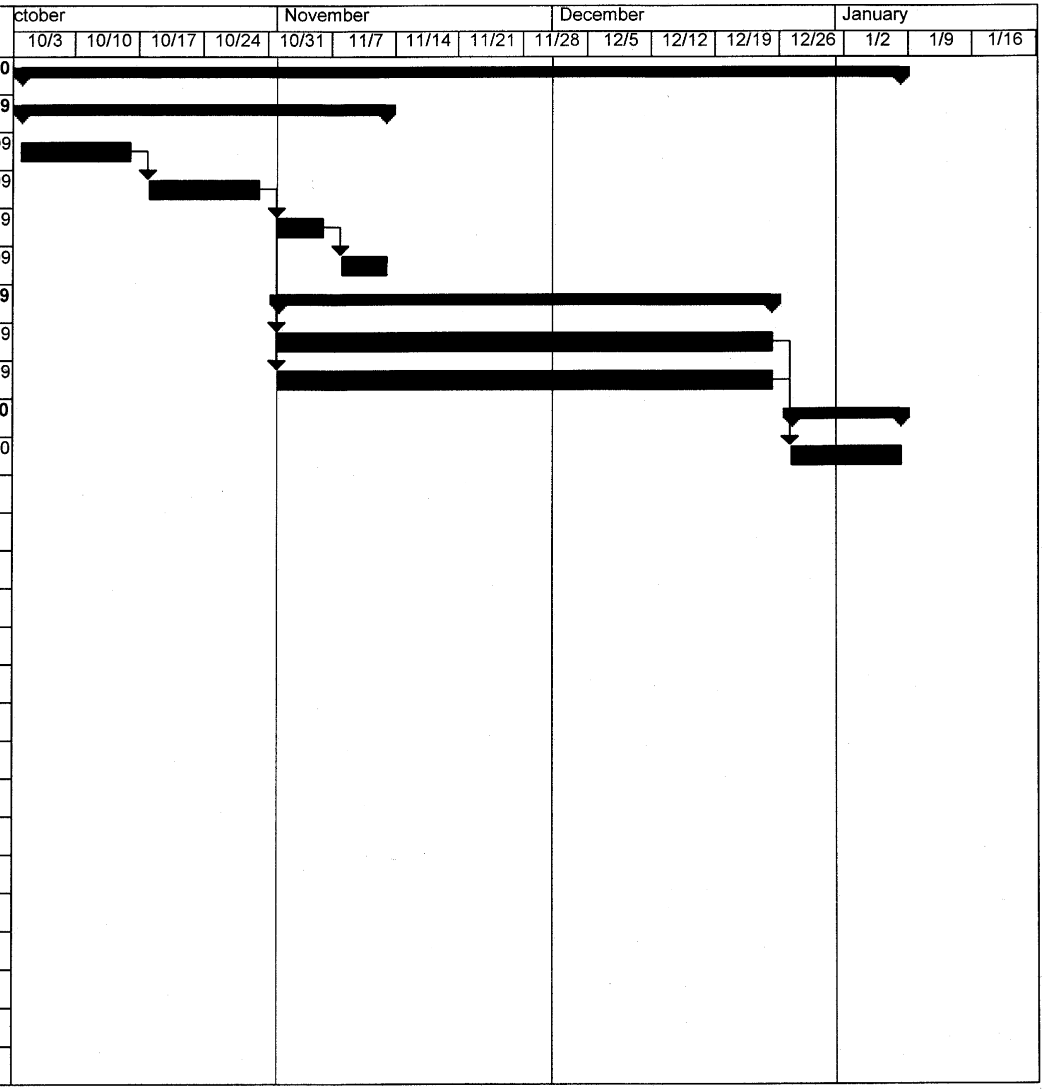

Figure 10. Subtask 3.1.6 Schedule

ID	Task Name	Start	Finish
1	**DCS**	**Mon 10/4/99**	**Fri 2/25/00**
2	**Engineering**	**Mon 10/4/99**	**Fri 2/25/00**
3	Y2K compliance	Mon 10/4/99	Fri 10/8/99
4	Open I/O count	Mon 10/4/99	Fri 10/15/99
5	Configure new I/O	Mon 12/13/99	Fri 1/7/00
6	Review current graphics	Mon 10/4/99	Fri 10/8/99
7	Develop new graphics as needed	Mon 1/10/00	Fri 2/4/00
8	DEC reports	Mon 2/7/00	Fri 2/18/00
9	Generate electrical wiring diagrams	Mon 10/4/99	Fri 10/15/99
10	Point to point check	Mon 10/4/99	Fri 11/26/99
11	Schedule maintenance	Mon 10/4/99	Tue 10/5/99
12	Operator training	Mon 2/21/00	Fri 2/25/00
13	**Procurement**	**Mon 10/4/99**	**Fri 12/10/99**
14	Upgraded system	Mon 10/11/99	Fri 12/3/99
15	New console	Mon 10/4/99	Fri 11/26/99
16	Air conditioner	Mon 10/4/99	Fri 10/8/99
17	I/O modules	Mon 10/18/99	Fri 12/10/99
18	Conduit	Mon 10/18/99	Fri 10/22/99
19	Junction boxes	Mon 10/18/99	Fri 10/22/99
20	Cabling	Mon 10/18/99	Fri 10/22/99
21	**Installation**	**Mon 10/11/99**	**Fri 12/24/99**
22	New console	Mon 11/29/99	Wed 12/1/99
23	Air conditioner	Mon 10/11/99	Mon 10/11/99
24	I/O modules	Mon 12/13/99	Fri 12/24/99
25	Instrument wiring	Mon 10/25/99	Fri 11/5/99

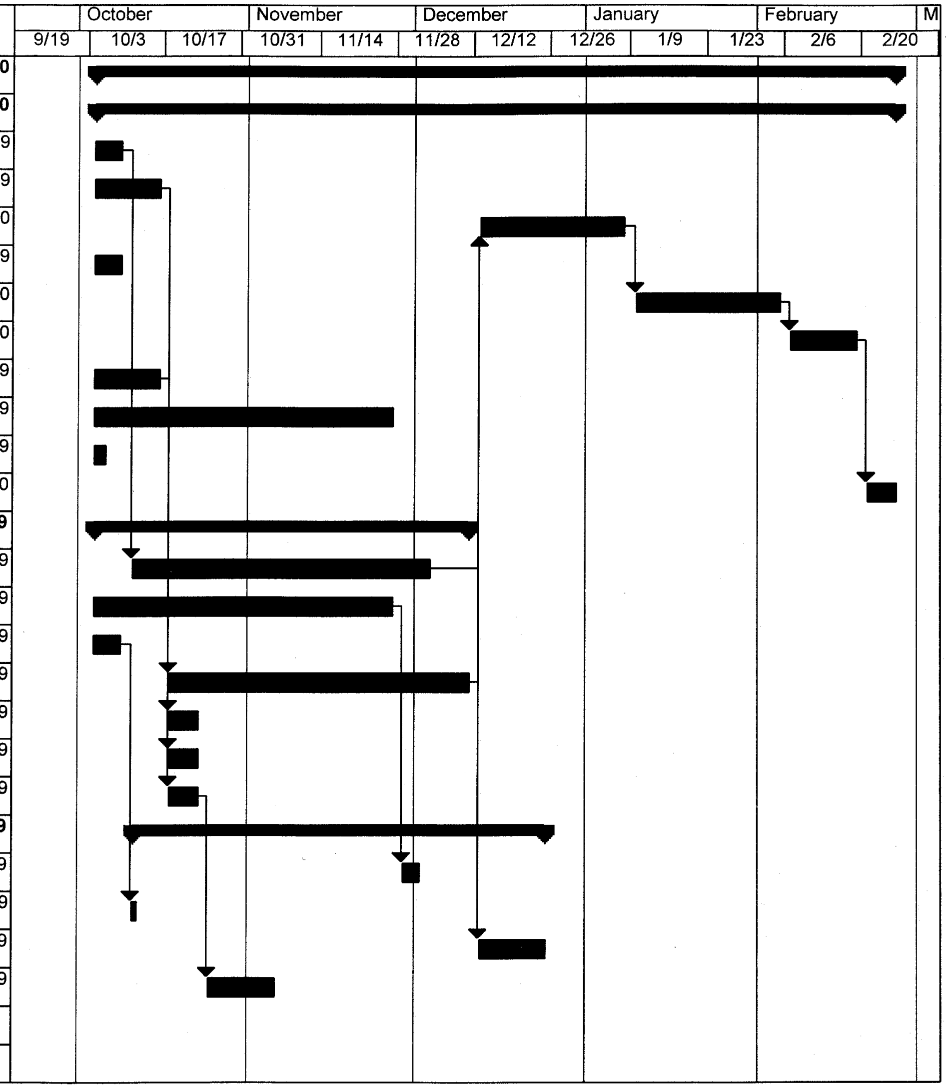

Figure 11. Subtask 3.1.7 Schedule

ID	Task Name	Start	Finish
1	**Materials Handling**	**Mon 10/4/99**	**Thu 1/6/00**
2	**Feedstock**	**Mon 10/4/99**	**Thu 1/6/00**
3	Identify fuel/sorbent	Mon 10/4/99	Tue 10/5/99
4	Chemical/PSD information	Wed 10/6/99	Thu 10/7/99
5	Locate source	Fri 10/8/99	Thu 10/14/99
6	Procure feedstocks	Fri 10/15/99	Thu 1/6/00
7	Arrange truck rental	Mon 10/4/99	Mon 10/4/99
8	**Process Sampling**	**Mon 10/4/99**	**Fri 12/24/99**
9	Identify samples to be taken	Mon 10/4/99	Fri 10/8/99
10	Produce sampling procedures	Mon 10/11/99	Fri 10/22/99
11	Define analyses to be performed	Mon 10/25/99	Fri 10/29/99
12	Procure sampling equipment	Mon 11/1/99	Fri 12/24/99

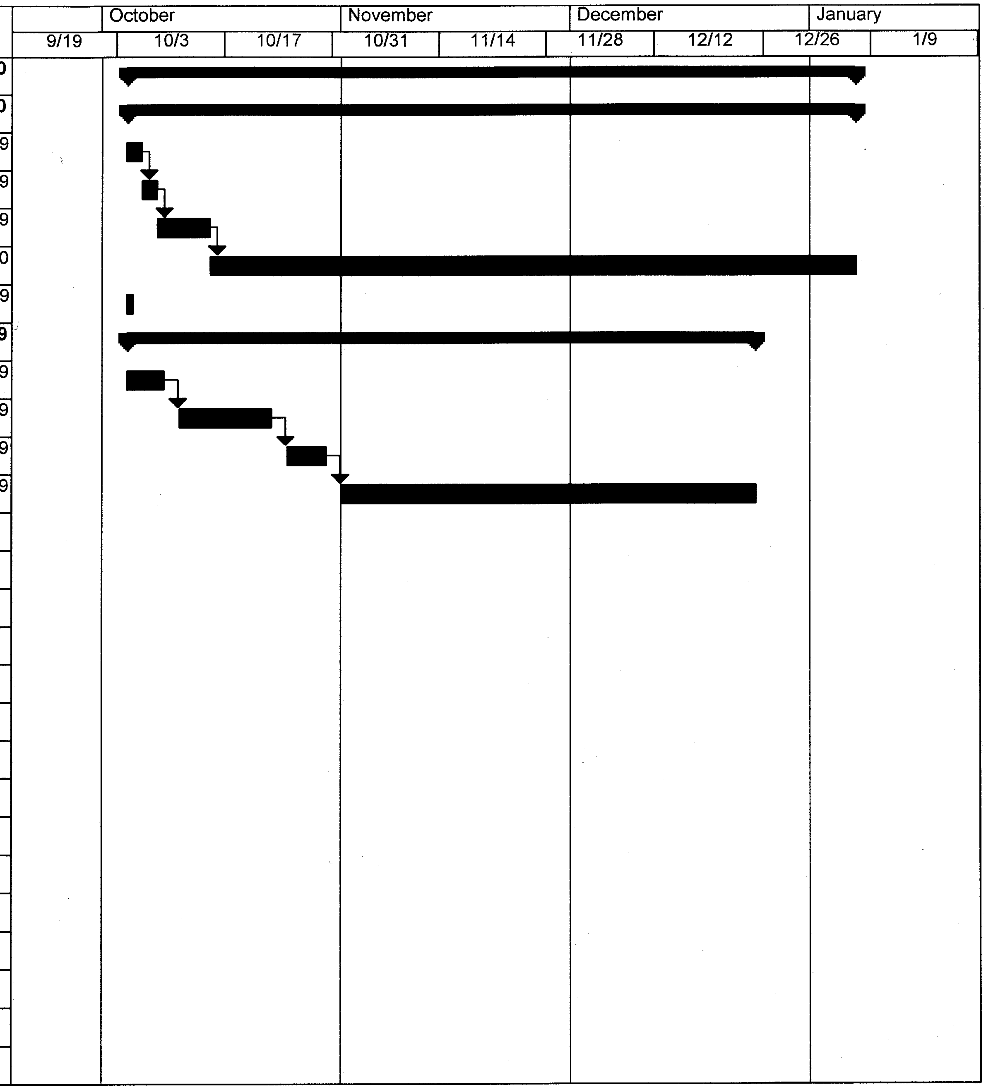

Figure 12. Subtask 3.1.8 Schedule

ID	Task Name	Start	Finish
1	**Environmental Compliance**	**Mon 10/4/99**	**Fri 12/3/99**
2	**Stack test**	**Mon 10/4/99**	**Fri 11/5/99**
3	Identify subcontractor	Mon 10/4/99	Fri 10/8/99
4	Review existing permits	Mon 10/11/99	Fri 11/5/99
5	Arrange stack testing	Mon 10/11/99	Fri 10/15/99
6	**CEM's**	**Mon 10/4/99**	**Fri 12/3/99**
7	Identify missing monitors	Mon 10/4/99	Fri 10/8/99
8	Install monitors	Mon 10/11/99	Fri 10/22/99
9	Re-connect sampling system	Mon 10/25/99	Fri 10/29/99
10	Procure certified cal gas	Mon 10/4/99	Fri 11/26/99
11	Calibrate CEM's	Mon 11/29/99	Fri 12/3/99
12	**Char Handling**	**Mon 10/4/99**	**Fri 10/29/99**
13	Develop solids removal plan	Mon 10/4/99	Fri 10/8/99
14	Order drums for storage	Mon 10/11/99	Fri 10/15/99
15	Generate MSDS for char	Mon 10/18/99	Fri 10/29/99

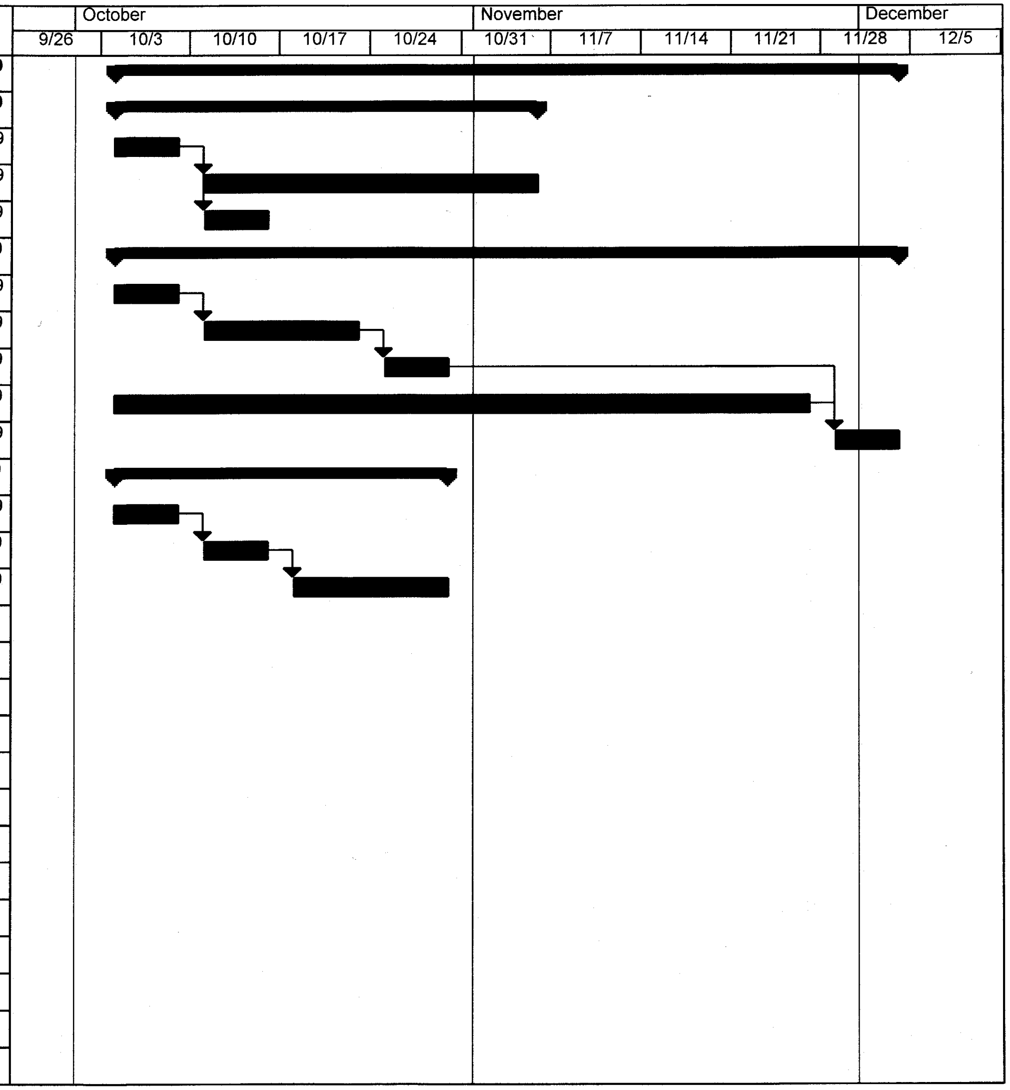

Figure 13. Subtask 3.1.9 Schedule

ID	Task Name	Start	Finish
1	**Utilities**	**Mon 10/4/99**	**Fri 12/17/99**
2	Nitrogen system	Mon 10/4/99	Fri 10/29/99
3	Boiler/steam	Mon 11/1/99	Fri 11/12/99
4	Process air	Mon 11/15/99	Fri 12/10/99
5	Instrument air	Mon 12/13/99	Fri 12/17/99
6	**Safety**	**Mon 10/4/99**	**Fri 11/12/99**
7	Pressure safety valve certification	Mon 10/4/99	Fri 10/8/99
8	Air pack stations	Mon 10/11/99	Fri 10/15/99
9	Eye wash system	Mon 10/18/99	Fri 10/22/99
10	Ambient air monitor calibration	Mon 10/25/99	Fri 10/29/99
11	Fire system	Mon 11/1/99	Fri 11/5/99
12	Total plant safety review	Mon 11/8/99	Fri 11/12/99
13	**Test Plan**	**Mon 10/4/99**	**Fri 11/19/99**
14	Review Lakeland operation	Mon 10/4/99	Fri 10/8/99
15	Identify process operating points	Mon 10/11/99	Fri 10/22/99
16	Identify critical test conditions (Heavy Metals)	Mon 10/25/99	Fri 10/29/99
17	Generate test matrix	Mon 11/1/99	Fri 11/19/99

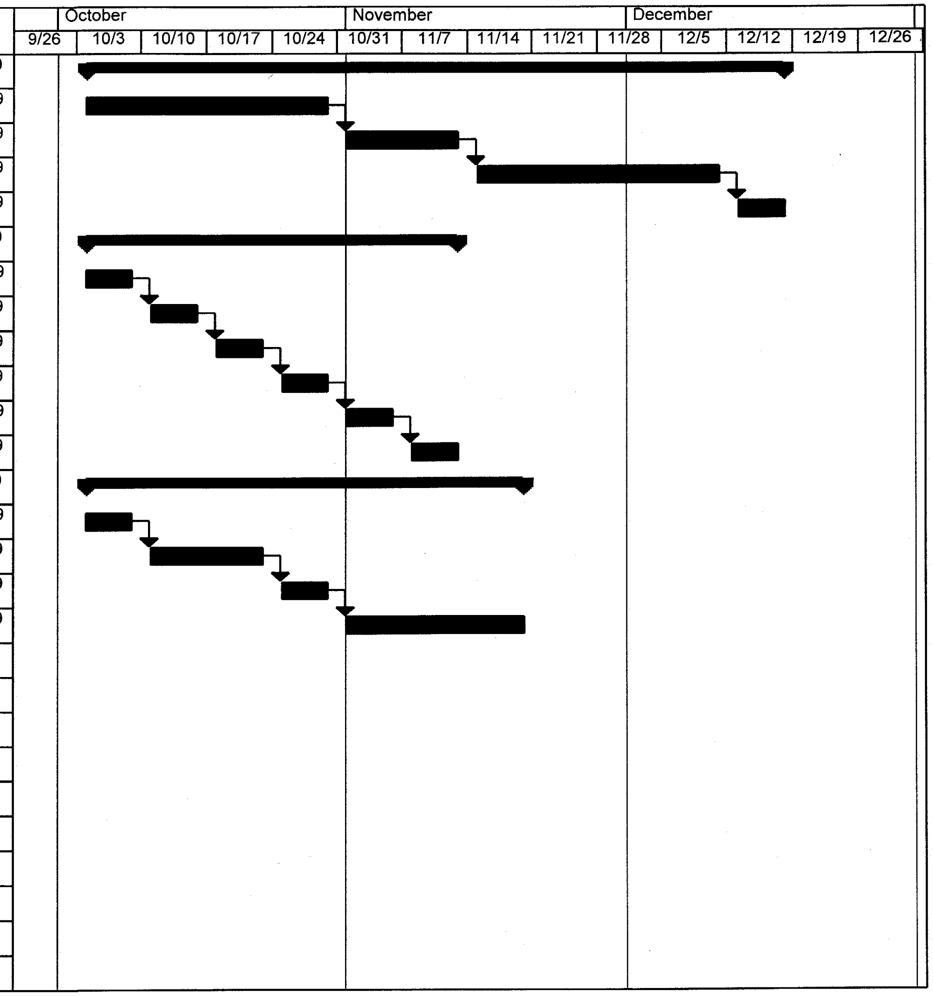

Figure 14. Subtasks 10 – 12 Schedule

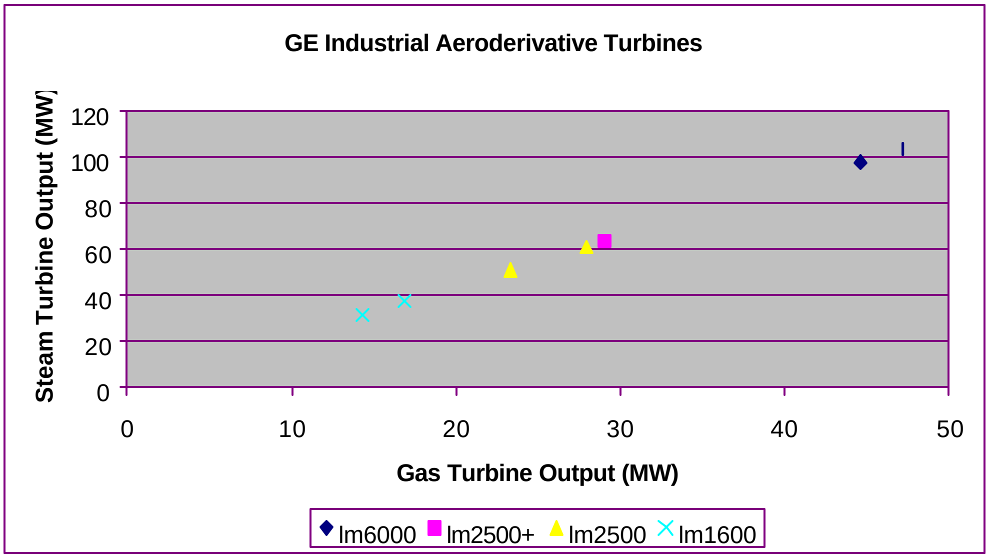

Figure 15: LM Series Gas Turbines

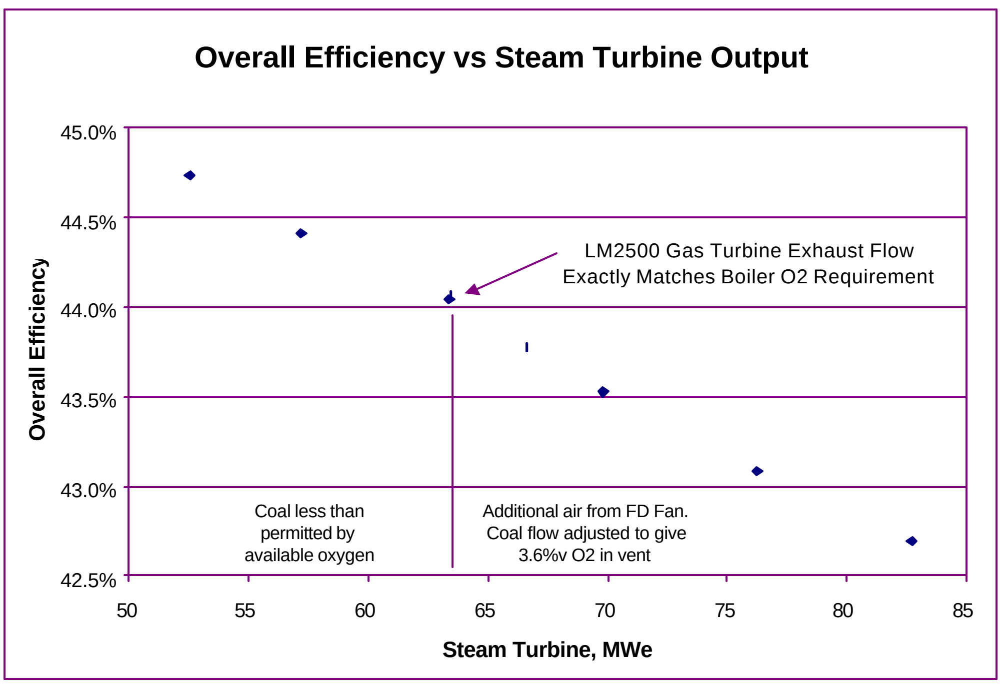

Figure 16: Overall Efficiency vs. Steam Turbine Power

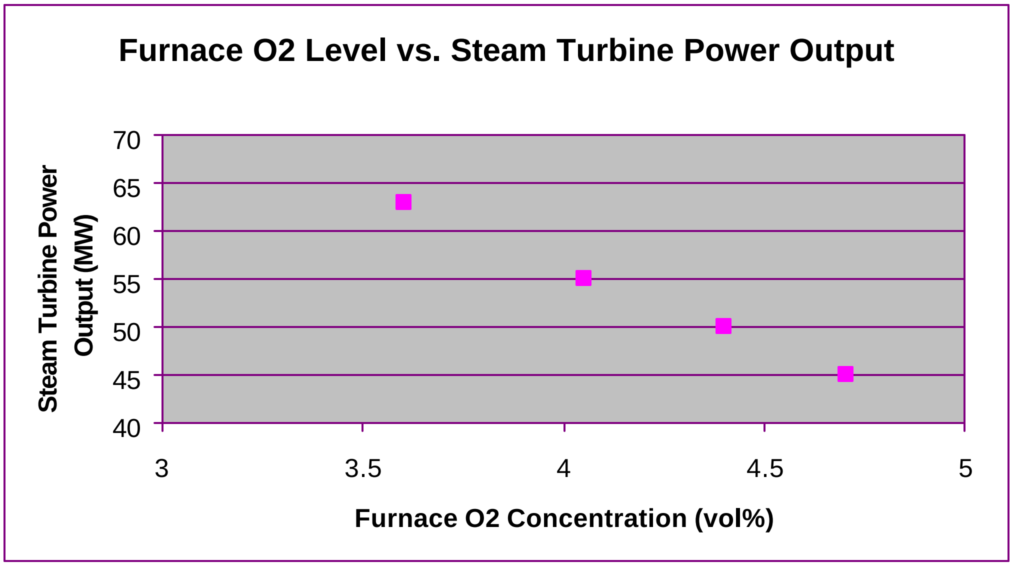

Figure 17: Furnace O_2 Level vs. Steam Turbine Power Output

A recent analysis for the repowering technology suggests broad market application for PC boilers less than 100 MW in the U.S. These older units are being sold to a variety of Independent Power Producers (IPP's), and these new owners have shown an interest to improve the performance of their generation assets through repowering. The HIPPS repowering concept, as depicted in Figure 3, illustrates how a gas turbine can be integrated with an existing PC boiler to improve both efficiency and power output. Depending upon the prevailing fuel price, the gas turbine can be fired either with natural gas or with a coal-derived syngas.

One of the most critical repowering issues is the selection of the proper gas turbine for the existing plant. Figure 15 identifies the range of "small" GE gas turbines available for repowering applications. These "LM Series" aeroderivative gas turbines are ideally suited for combined cycle retrofits of steam plants less than 100 MW. As indicated in Figure 15, the LM6000 gas turbine produces a nominal 50 MW, and when ideally coupled in combined cycle with a 100 MW steam turbine, produces a total power output of 150 MW. On the lower end, the LM1600 (16 MW) can be employed to retrofit a nominal 40 MW steam turbine. These smaller units can be used most effectively to serve the needs of industrial customers. It should be noted that these aeroderivative gas turbines can support the 20% off-board extraction required for the pyrolyzer syngas production. These turbines were originally designed to extract a significant amount of air for cabin pressurization and for a variety of military purposes.

Figure 16 illustrates how the overall plant efficiency is effected by the size of the steam turbine. This figure assumes repowering with the LM2500 gas turbine for all data points. The point at 44% efficiency and 63 MW represents the condition where the gas turbine exhaust (14% O2) provides an exact match with the existing boiler to maintain full load and a furnace oxygen concentration of 3.6% (vol.). As the size of the steam turbine is increased, the overall efficiency of the plant is reduced. Based on the figure, repowering an 85 MW steam turbine with an LM 2500 gas turbine would provide an overall plant efficiency of 42.5%. The plant efficiency is reduced with increasing steam turbine to gas turbine size because the brayton cycle is more efficient than the rankine cycle. It should be noted that as the steam turbine power output increases relative to the gas turbine, additional air flow is required since the gas turbine exhaust cannot provide sufficient oxygen for full steam turbine load. In this instance a separate FD fan will be required for the plant. Conversely, the overall plant efficiency increases as the size of the steam turbine decreases relative to that of the gas turbine. Based on figure 16, repowering a 50 MW steam turbine with an LM 2500 gas turbine would result in a plant efficiency of approximately 45%. In this particular case, the gas turbine exhaust provides more oxygen than is required for typical boiler combustion, and if this total flow is still sent to the boiler, the furnace oxygen level will be increased. Depending upon the specific operation of the boiler and the fuel feedstock employed, there may be a practical limit to how far the oxygen concentration can be increased. Figure 17 illustrates the relationship between the steam turbine power output and the furnace oxygen levels for an LM2500 repowering arrangement. The repowering of a 50 MW boiler would result in a 4.4% (vol.) furnace oxygen concentration.